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(54) Method to regenerate a particulate filter

(57) The Invention relates to a Method to regenerate a particulate filter, in particular a Diesel paticulate filter (DPF), whereby the particulate filter is arranged in an exhaust passage for receiving an exhaust gas from an internal combustion engine, in particular from a Diesel engine, whereby the particulate filter traps particulates contained in the exhaust gas, so that soot is collected inside the particulate filter. The method comprises the steps of (i) initiating an ignition of soot inside the particulate filter, and (ii) actuating a reduction of the exhaust gas mass flow through the filter, preferentially together with increasing concentration of oxygen in the exhaust gas, for example by means of using engine operating conditions with lighter load, whereby the steps (i) and (ii) can be repeated several times with a determined frequency so that a desired degree of filter regeneration is achieved.

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Description

[0001] The Invention relates to a Method to regenerate a particulate filter, in particular a Diesel paticulate filter (DPF), whereby the particulate filter is arranged in an exhaust passage for receiving an exhaust gas from an internal combustion engine, in particular from a Diesel engine, whereby the particulate filter traps particulates included in the exhaust gas, so that soot is collected inside the particulate filter.

[0002] Methods to regenerate particulate filters, in particular Diesel particulate filters are known in prior art.

[0003] The EP 0 528 289 B1 relates to a device for removing particulates in the exhaust gas of a diesel engine. The device comprises a filter arranged in an exhaust line for receiving the exhaust gas from the diesel engine, the filter being capable of trapping particulates included in the exhaust gas. The device further comprises heating means arranged adjacent to the filter for generating heat in the filter. Further air supplying means for supplyng air into the filter for incinerating the particulates , and control means for controlling an amount of air flow for obtaining a desired incineration performance of the particulates trapped in the filter are comprised by the device. The control means comprises detecting means for detecting the amount of residual unburnt particulates upon the incineration process, and air flow amount control means responsive to the detected amount of residual unburnt particulates for controlling the amount of the air flow used in the subsequent incineration process.

[0004] The EP 0 528 289 B1 discloses a device for purifying particulates in the exhaust gas of a diesel engine, whereby the control means comprises effective area detecting means for detecting the value of the effective area of the filter before commencement of trapping of the particulates by the filter, and determining means for determining the amount of the air to be introduced into the filter in the subsequent incineration process in accordance with the detected value of the effective area.

[0005] The EP 0 528 289 B1 describes that during a filter regeneration the periphery of the filter may not be regenerated completely, leading to a more and more clogged filter after regeneration. In order to regenerate the DPF additional hardware is used. In the EP 0 528 289 B1 it is disclosed, that in the centre of the filter a temperature of 900°C is to be achieved, so that in the periphery a temperature of 500°C is achieved. These high temperature gradients will certainly decrease filter life time, and limit the soot load, which in turn will lead to the requirement of more frequent regenerations and hence a larger fuel consumption.

[0006] The additional hardware, like for example the heating device, the secondary air system, including an air pump adds hardware costs, takes up package space and uses a lot of energy, leading to a high operating cost.

[0007] Further disadvantage of the EP 0 528 289 is to be seen in the fact, that a by-pass valve is used in order to lead exhaust gases to the environment without passing through the filter, which will lead to emissions of particulates during all the time when the by-pass is activated.

[0008] Although the EP 0 528 289 B1 uses pressure difference measurements for determining the amount of soot present in the filter, no information is available on the axial distribution of the soot after a (partial) regeneration.

[0009] Therefore the objective of the present invention is to provide a better method to regenerate a particulate filter which achieves a complete and fast, preferentially in a short time, regeneration of the particulate filter, thus saving energy, leading to a low fuel penalty for a driver of a vehicle without using additional hardware so that extra hardware costs, package space and total vehicle mass is saved leading to a more robust design.

[0010] The objective is solved by the steps: Initiating an ignition of soot inside the particulate filter, and actuating a reduction of the exhaust gas mass flow through the filter, whereby the a.m. steps are repeated several times with a determined frequency so that a desired degree of filter regeneration is achieved.

[0011] Initiating an ignition of soot inside a filter can be performed by increasing temperature of the filter utilizing in-cylinder combustion using multiple injections, and/or by increasing engine speed and/or load, and/or by using post-cylinder fuel or other combustible compound injection/addition into the post-combustion gases and burning this combustible compound over an oxidation catalyst placed in the exhaust gas passage between combustion chamber(s) and (diesel) particulate filter, or over an active catalyst deposited onto the (diesel) particulate filter material.

[0012] To detect the initiation of soot combustion inside a filter, monitoring means such as measurements of the exhaust gas mass flow, fuel consumption, exhaust gas and internal filter temperatures, exhaust gas backpressure, can be applied.

[0013] In a first embodiment reducing the exhaust gas mass flow through the filter, preferentially together with increasing concentration of oxygen in the exhaust gas, can be done by means of switching the engine into conditions providing lower mass flow and/or higher oxygen content (for example idling), if necessary — together with decreasing amount of fuel added for heating a particulate filter.

[0014] In a second embodiment reducing the exhaust gas mass flow through the filter, preferentially together with increasing concentration of oxygen in the exhaust gas, can be done by means of activating valve(s) allowing only a controllable portion of the exhaust gas to pass through the filter, while the rest of the exhaust gas to by-pass the filter, if necessary - together with decreasing amount of fuel added for heating a particulate filter.

[0015] In a third embodiment reducing the exhaust gas mass flow through the filter, preferentially together with in-

creasing concentration of oxygen in the exhaust gas, can be done by means of activating a system that separately supplies air and/or exhaust gas to the filter at flow rate and with oxidant content that are sufficient to maintain the filter regeneration.

[0016] In the following some examples of results by using the inventional method are shown. The used abbreviations in the respective tables are defined as:

SL, g/L-	Soot loading, gram/liter,
DPF-	Diesel Particulate Filter,
SiC-	silicon carbide (filter material)
5.66"D x 6" L-	DPF diameter (D) and length (L) in inches,
200 cpsi-	number of cells per square inch,

[0017] Example 1 a shows versus example 1 b (Table 1), that initiating regeneration during 2 min of post-injecting, followed by decreasing gas flow through a filter together with cutting off fuelling results in high regeneration efficiency (96%); while without decreasing gas flow and without cutting fuelling off, similar regeneration efficiency can be achieved only after 10 min of post injection causing higher fuel consumption compared to 1a.

Table 1

Ex. No.	Particulate Filter	Description	SL, g/L	Duration of post injection, s	Regeneration method and media	Regeneration efficiency, % mass
1 a	DPF#1	Catalysed SiC filter; 5,66"D x 6"L; 200cpsi	8.5	123	Exhaust gas; after cutting post-injection, mass flow of 30+/-20 kg/hr	96
1 b	DPF#1	Catalysed SiC filter; 5,66"D x 6"L; 200cpsi	7.5 -*- -*-	300" 600" 900"	Exhaust gas; 600°C upstream of the filter continuously during 15 min with post-injection, mass flow of 90+/-10 kg/hr	55% 90% 100%

[0018] Example 1a shows versus example 1c (Table 2), that initiating regeneration during 2 min of post-injecting, followed by decreasing gas flow through a filter results in high regeneration efficiency (96%); with cutting fuelling off but without decreasing gas flow, regeneration efficiency is much lower (only 27%).

Table 2

Ex. No.	Particulate Filter	Description	SL, g/L	Duration of post injection, s	Regeneration method and media	Regeneration efficiency, % mass
1 a	DPF#1	Catalysed SiC filter; 5,66"D x 6"L; 200cpsi	8.5	123	Exhaust gas; after cutting post-injection, mass flow of 30+/-20 kg/hr	96

(continued)

Ex. No.	Particulate Filter	Description	SL, g/L	Duration of post injection, s	Regeneration method and media	Regeneration efficiency, % mass
1c	DPF#1	Catalysed SiC filter; 5,66"D x 6"L; 200cpsi	7.6	123	Exhaust gas; before and after cutting post-injection, mass flow of 90+/-10 kg/hr	27

[0019] Examples 2a and 2b (Table 3) show that according to the method of the present invention, either exhaust gas, or air can be used for efficient regeneration of a particulate filter.

Table 3

Ex. No.	Particulate Filter	Description	SL, g/L	Duration of post injection, s	Regeneration method and media	Regeneration efficiency, % mass
2a	DPF#2	Catalysed SiC filter; 5,66"D x 6"L; 300cpsi	6.3	119	Exhaust gas; after cutting post-injection, mass flow of 30+/-20 kg/hr	69.5
2b	DPF#2	Catalysed SiC filter; 5,66"D x 6"L; 300cpsi	6.7	115	After cutting post-injection, air with mass flow of 30+/-20 kg/hr	71.1

[0020] Examples 3a-3e (Table 4) show that the method of the present invention is applicable to un-catalysed filters

Table 4

Ex. No.	Particulate Filter	Description	SL, g/L	Duration of post injection, s	Regeneration method and media	Regeneration efficiency, % mass
3a	DPF#3	Uncoated SiC; 5,66"D x 6"L; 200 cpsi	3.40	172	Exhaust gas; after cutting post-injection, mass flow of 30+/-20 kg/hr	94.0
3b	-"-	-"-	5.40	175	-"-	90.9
3c	-"-	-"-	8.43	130	-"-	74.3
3d	-"-	-"-	11.30	123	-"-	65.9
3e	-"-	-"-	12.69	121	-"-	67.7

[0021] Examples 4a-4g (Table 5) show that the method of the present invention is applicable to processes in which regeneration is assisted by fuel borne additive.

Table 5

Ex. No.	Particulate Filter	Description	SL, g/L	Duration of post injection, s	Regeneration method and media	Regeneration efficiency, % mass
4a	DPF#4	Uncoated SiC X00 cpsi; 5,66"D x 10"L; Ce-Fe fuel borne additive assisted regeneration	3.95	126	Exhaust gas; after cutting post-injection, mass flow of 30+/-20 kg/hr	90.8
4b	-"-	-"-	5.02	70	-"-	98.1
4c	-"-	-"-	5.77	84	-"-	93.3
4d	-"-	-"-	7.98	40	-"-	97.3
4e	-"-	-"-	9.70	66	-"-	95.8
4f	-"-	-"-	11.45	70	-"-	96.0
4g	-"-	-"-	14.12	51		96.0

[0022] Examples 5a-5d (Table 6) show that the method of the present invention is applicable to the catalysed DPF prepared on the silicon carbide 200 cpsi DPF support (6"-long filter).

Table 6

Ex. No.	Particulate Filter	Description	SL, g/L	Duration of post injection, s	Regeneration method and media	Regeneration efficiency, % mass
5a	DPF #5	Catalysed SiC filter; 5,66"D x 6"L; 200cpsi	4.6	116	Exhaust gas; after cutting post-injection, mass flow of 30+/-20 kg/hr	45.5
5b	-"-	-"-	5.8	156	-"-	100
5c	-"-	-"-	8.5	157	-"-	97.6
5d	-"-	-"-	9.7	147	-"-	93.6

[0023] Examples 6a-6g (Table 7) show that the method of the present invention is applicable to the longer catalysed filters; in this case, results for DPF prepared on the silicon carbide 300 cpsi DPF support are shown (10"-long filter).

Table 7

Ex. No.	Particulate Filter	Description	SL, g/L	Duration of post injection, s	Regeneration method and media	Regeneration efficiency, % mass
6a	DPF #6	Catalysed SiC filter; 5,66"D x 10"L; 300cpsi	3.7	101	Exhaust gas; after cutting post-injection, mass flow of 30+/-20 kg/hr	50.0
6b	-"-	-"-	5.2	117	-"-	68.2
6c	-"-	-"-	5.7	156	-"-	88.1
6d	-"-	-"-	7.0	173	-"-	100

(continued)

Ex. No.	Particulate Filter	Description	SL, g/L	Duration of post injection, s	Regeneration method and media	Regeneration efficiency, % mass
6e	-"-	-"-	7.8	117	-"-	79.6
6f	-"-	-"-	9.0	101	-"-	91.4
6g	-"-	-"-	10.2	96	-"-	100

[0024] Examples 7a-7g (Table 8) show that the method of the present invention is applicable to even much longer catalysed filters; in this case, results for DPF prepared on the silicon carbide 300 cpsi DPF support are shown (14"-long filter).

Table 8

Ex. No.	Particulate Filter	Description	SL, g/L	Duration of post injection, s	Regeneration method and media	Regeneration efficiency, % mass
7a	DPF #7	Catalysed SiC filter; 5,66"D x 14"L; 300cpsi	4.2	96	Exhaust gas; after cutting post-injection, mass flow of 30+/-20 kg/hr	61.3
7b	-"-	-"-	4.9	100	-"-	45.7
7c	-"-	-"-	6.2	104	-"-	48.1
7d	-"-	-"-	6.5	139	-"-	89.5
7e	-"-	-"-	7.6	136	-"-	92.1
7f	-"-	-"-	8.7	129	-"-	95.7
7g	-"-	-"-	9.6	115	-"-	99.1

[0025] Examples 8a-8d (Table 9) show that the method of the present invention is applicable to the catalysed DPF prepared on the refractory oxide (cordierite) 300 cpsi DPF support (6"-long filter).

Table 9

Ex. No.	Particulate Filter	Description	SL, g/L	Duration of post injection, s	Regeneration method and media	Regeneration efficiency, % mass
8a	DPF #8	Catalysed SiC filter; 5,66"D x 6"L; 300cpsi	2.0	116	Exhaust gas; after cutting post-injection, mass flow of 30+/-20 kg/hr	81.3
8b	-"-	-"-	3.8	133	-"-	66.7
8c	-"-	-"-	6.2	99	-"-	88.2
8d	-"-	-"-	7.5	97	-"-	94.0

[0026] As the above examples show, each regeneration carried out via the inventional method provides nearly complete regeneration of the particulate filter. Mainly insulated particulate filters and particulate filters with a high thermal conductivity are used, so that radial temperature profiles are reduced. The reduced radial temperature profiles lead advantageously to an increased particulate filter lifetime and hence a smaller fuel consumption.

[0027] Advantageously only an engine calibration is required, which can be fully controlled by a known motor man-

agement system, so that no extra package space and hardware costs is used. Even the energy required for heating the particulate filter is reduced.

[0028] Because of the fact, that the exhaust gases in the preferred embodiment pass through the particulate filter at every time, even during regeneration, emissions to the environment are reduced.

[0029] With the inventional method a complete and fast regeneration of the particulate filter is achieved, thus saving energy, leading to a low fuel penalty for the driver. The complete regeneration can be achieved within a short time, saving extra hardware costs, saving package space and total vehicle mass, leading to a more robust design since the method is implemented fully in the motor management system.

[0030] The preferred embodiment of the invention includes, after initiating particulate regeneration inside the filter, putting the engine into low mass-flow and/or higher oxygen content conditions to support regeneration without any other means such as secondary air supply, external heater, additional valves, pipes or by-passes.

Claims

1. Method to regenerate a particulate filter, in particular a Diesel paticulate filter (DPF), whereby the particulate filter is arranged in an exhaust passage for receiving an exhaust gas from an internal combustion engine, in particular from a Diesel engine, whereby the particulate filter traps particulates included in the exhaust gas, so that soot is collected inside the particulate filter
   characterized by
   the steps of (i) initiating an ignition of soot inside the particulate filter, and (ii) actuating a reduction of the exhaust gas mass flow through the filter, whereby the steps (i) and (ii) can be repeated several times with a determined frequency so that a desired degree of filter regeneration is achieved.

2. Method according to claim 1,
   characterized in, that
   the initiating of the ignition of soot inside the (diesel) particulate filter is performed by increasing temperature of the (diesel) particulate filter by in-cylinder combustion with multiple post injections.

3. Method according to claim 1 or 2,
   characterized in, that
   the initiating of the ignition of soot inside the (diesel) particulate filter is performed by increasing temperature of the (diesel) particulate filter by increasing engine speed and/or load.

4. Method according to one of the preceding claims,
   characterized in, that
   the initiating of the ignition of soot inside the (diesel) particulate filter is performed by increasing temperature of the (diesel) particulate filter by combustible compound injection into post combustion gases and burning the said combustible compound over an oxidation catalyst placed in the exhaust gas passage between combustion chamber(s) and the (diesel) particulate filter.

5. Method according to claim 4,
   characterized in, that
   the combustible compound preferably is normal fuel.

6. Method according to one of the preceding claims,
   characterized by
   monitoring means in order to detect the initiation of soot combustion inside the (diesel) particulate filter.

7. Method according to one of the preceding claims,
   characterized in, that
   the exhaust gas mass flow through the (diesel) particulate filter is reduced preferentially with increasing concentration of oxygen in the exhaust gas, by means of switching the engine into conditions providing lower mass flow.

8. Method according to one of the preceding claims,
   characterized in, that
   the exhaust gas mass flow through the (diesel) particulate filter is reduced preferentially with increasing concentration of oxygen in the exhaust gas, by means of switching the engine into conditions providing higher oxygen content.

9. Method according to one of the preceding claims,
characterized in, that
the exhaust gas mass flow through the (diesel) particulate filter is reduced preferentially with increasing concentration of oxygen in the exhaust gas, by means of activating a system that separately supplies air to the (diesel) particulate filter at flow rate and with oxidant content that are sufficient to maintain the (diesel) particulate filter regeneration.

10. Method according to one of the preceding claims,
characterized in, that
the exhaust gas mass flow through the (diesel) particulate filter is reduced preferentially with increasing concentration of oxygen in the exhaust gas, by means of activating a system that separately supplies exhaust gas to the (diesel) particulate filter at flow rate and with oxidant content that are sufficient to maintain the (diesel) particulate filter regeneration.

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EUROPEAN SEARCH REPORT

Application Number
EP 05 10 6289

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	30 November 2005	Trotereau, D

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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